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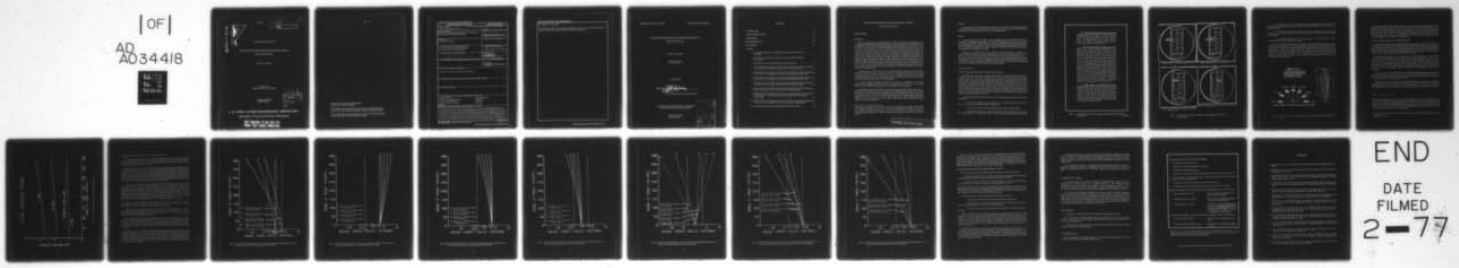

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Technical Memorandum 28-76

SIMPLIFIED PROCEDURES FOR ENGAGING MOVING TARGETS WITH THE M72A2 LAW

Dominick J. Giordano

November 1976
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U. S. ARMY HUMAN ENGINEERING LABORATORY
Aberdeen Proving Ground, Maryland

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At the request of the U.S. Army Infantry School, the U.S. Army Human Engineering Laboratory investigated the lead-line design in the M72A2 light antitank weapon (LAW) sight, and the current procedures by which gunners engage moving targets with the LAW. The investigation disclosed the fact that, while the field manual for the LAW (FM 23-33) describes the LAW lead lines as "representing 15 miles per hour target speed," the lines are really 6-mph lead lines. It was concluded that the current rules for engaging moving targets with the LAW are incomplete, complex and confusing--and, if used, give less effectiveness than could be attained with a greatly simplified set of rules. It is

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20. Abstract (Continued)

recommended that the Infantry adopt the proposed new rules that can increase the LAW gunner's effectiveness and reduce the training time for potential LAW gunners.

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SIMPLIFIED PROCEDURES FOR ENGAGING MOVING TARGETS WITH THE M72A2 LAW

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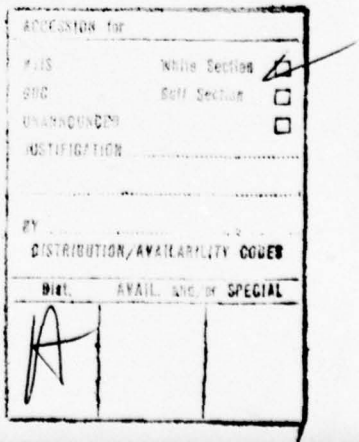

CONTENTS

SIMPLIFIED PROCEDURES FOR ENGAGING MOVING TARGETS WITH THE M72A2 LAW

INTRODUCTION

Background

The U.S. Army Human Engineering Laboratory (HEL) undertook this investigation as a consequence of telephone discussions initiated by U.S. Army Infantry Center (USAIC) personnel, to determine why the LAW hit probabilities against moving targets that were recorded in a field experiment (10) were lower than those predicted from theoretical performance curves. The investigation revealed these facts: (a) the lead lines in the LAW sight differed from those in previous antitank weapon sights; (b) contrary to FM 23-33 (2), the lead lines were designed for a target speed of 6 mph, not 15 mph; and (c) the procedures for engaging moving targets were complex and confusing. Simplified procedures were developed for engaging moving targets with the LAW out to the maximum range on the sight (350 meters), and they were forwarded to the USAIC (8). When discussions with USAIC personnel indicated that future LAW gunners would be trained to engage moving targets only at ranges of 200 meters or closer, the procedures were simplified further and again forwarded to the USAIC (9). The re-simplified procedures were also sent to the U.S. Army Training and Doctrine Command (TRADOC) headquarters in response to their message (12) about adopting the new procedures for training future LAW gunners, and for inclusion in a training bulletin.

Subsequently, in a presentation to the Army War College (6), the Deputy Chief of Staff for Training at TRADOC, Major General Gorman, briefly described the problem in the LAW's lead-line design. This resulted in inquiries from U.S. Army Materiel Development and Readiness Command Laboratories (Picatinny Arsenal and Rock Island Arsenal) to obtain further details about what appeared to be an error in the sight design.[a]

A recently released TRADOC bulletin (7) incorporates a modification of the HEL procedures for engaging moving targets with the LAW, but merely alludes to the lead-lines design--it merely states that the lead lines are for a 6-mile-per-hour target speed.

Undoubtedly, there will be further inquiries regarding: (a) whether there was an error in designing the LAW sight; (b) why the procedures for engaging moving targets with the LAW differ from those for previous antitank weapons; and (c) what rationale was used in developing the simplified procedures. Therefore, although the findings of this investigation have already been adopted, this report is necessary in order to answer these inquiries. Also, by disseminating the results of this investigation, we hope to avoid a similar sight design problem with future LAW-type weapons (e.g., VIPER).

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[a]Although, as is pointed out later, the lead lines were not designed incorrectly, the stadia lines were designed incorrectly (3, 5). Also, it is well known that the plastic sight reticle has poor optical qualities (images near the edge of the reticle are distorted). In addition, the spacing between the sight's range lines is incorrect, because the design specifications for the spacing are incorrect.

Purpose

The purpose of this investigation is to examine the current rules for leading moving targets with the LAW, show theoretical performance when a gunner attempts to use them, and devise a simplified set of rules which, when used, will increase effectiveness.

Method

A four-fold approach was taken in the investigation. First, we examined the current procedures for engaging moving targets with the LAW and compared them with procedures used for other types of ballistic antitank weapons. Second, we attempted to determine the reasons for differences between the procedures. Third, we examined theoretical hitting performance against moving targets. Fourth, based on theoretical findings, we developed a simplified set of procedures for engaging moving targets with the LAW.

Theoretical hitting performance was examined by plotting the point of impact on a tank-size target as a function of target range and speed, amount of lead, and aiming point on the target. In taking this approach we assume that there is no bias in the man/weapon system; i.e., the points of impact are mean points of impact, and the weapon-and-gunner combination causes some dispersion about these means. The resultant graphs are somewhat analogous to graphs of hit probability, in that hit probability is highest for a round impacting at the center of the target and decreases as miss distance from the center of the target increases.

Discussion of Findings

A. Comparison Between Moving-Target Engagement Procedures

The LAW sight is similar to the sights on other U.S. Army ballistic antitank weapons--for example, the 57-, 75-, and 90mm recoilless rifles, and the 3.5-inch rocket launcher--in that it contains range lines, stadia lines and lead lines. However, the LAW sight requires different procedures for applying lead when engaging a moving target. The M90D sight on the 75mm recoilless rifle is typical of the sights on the other weapons; it has lead marks spaced at five-mil intervals on both sides of the reticle's centerline, and "three leads" (15 mils) are required for each 10-mph speed increment. To lead a moving target with this sight, the gunner estimates the target's crossing speed, selects the appropriate lead mark, and aligns that lead mark on the target's center of mass. Figure 1 shows the procedures for leading moving targets with the LAW sight, and explanatory figures reproduced from FM 23-33, paragraph 25 (2); the differences between these and the previous procedures are easily seen.

The LAW sighting procedures are also more complex and confusing, and they raise a number of questions:

1. How much additional lead is required for a 15-mph target moving across the gunner's line of sight, at a distance greater than 200 meters?

2. Is this change in lead required for targets at other speeds and aspect angles?

3. Assuming the instructions imply linear interpolation for speeds less than 15 mph, why does Figure 15 in FM 23-33 (2) show 1/3 lead for a 10-mph target, instead of 2/3 lead?

(2) Targets moving directly toward or away from the gunner. The gunner must use a half stadia sight picture to estimate the range to the target, locate this range on the vertical range line (fig 13), and place this point so the range segment is on the target center of mass. If the target is moving directly away from the gunner, the procedure would be the same.

(3) Targets moving directly across the gunner's front. With a target moving perpendicular to the gunner's line of sight, the gunner must estimate the range to the target and the speed the target is moving. The sight reticle should be placed on the target so that the vertical range line is always in front of the target's direction of travel. With the correct range marking lined up on the target, the rocket launcher must be moved horizontally in the direction of the target's movement so that the lead cross opposite the range is lined up on the forward section of the target (fig 14). With this line of aim, and the target moving at 15 miles per hour at a distance less than 200 meters, the rocket should strike the rear third of the target. If the target is at a distance greater than 200 meters the gunner estimates additional lead. The lead marks on the M72 sight reticle indicate 15 miles per hour of speed. If the gunner estimates the target's speed as less than 15 miles per hour he must interpolate the amount of lead necessary to engage the target by visualizing a point on the reticle (fig 15).

(4) Targets moving at an angle toward or away from the gunner. When the target is moving toward the gunner at an angle where more of the front of the target is visible than the side, the gunner should estimate the range to the target and place that range on the forward edge of the target (fig 16). If the target is moving at an angle where more of the side is visible than the front the gunner would estimate the range, estimate the speed it appears to be moving, and apply one-half lead to the forward edge of the target (fig 17).

Figure 1. LAW sighting procedures for engaging moving targets (from FM 23-33, July 1970) (2). (Continued)

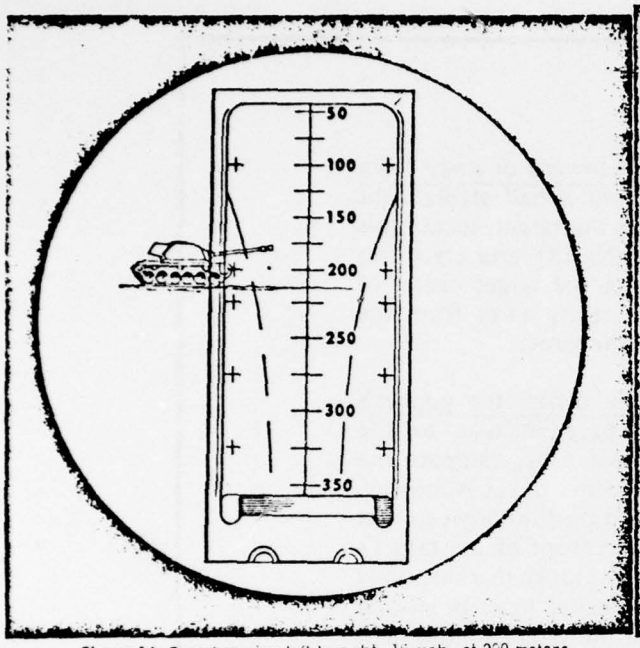

Figure 14. Target moving left to right, 15 mph, at 200 meters.

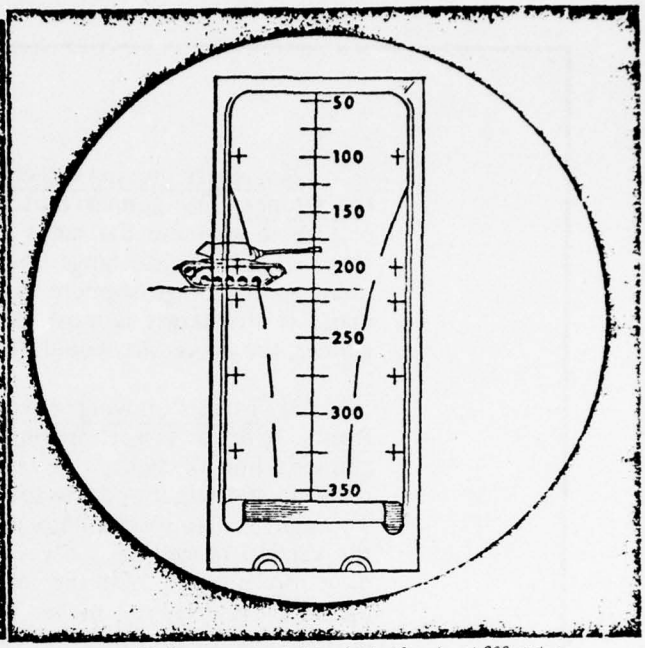

Figure 15. Target moving left to right, 10 mph, at 200 meters.

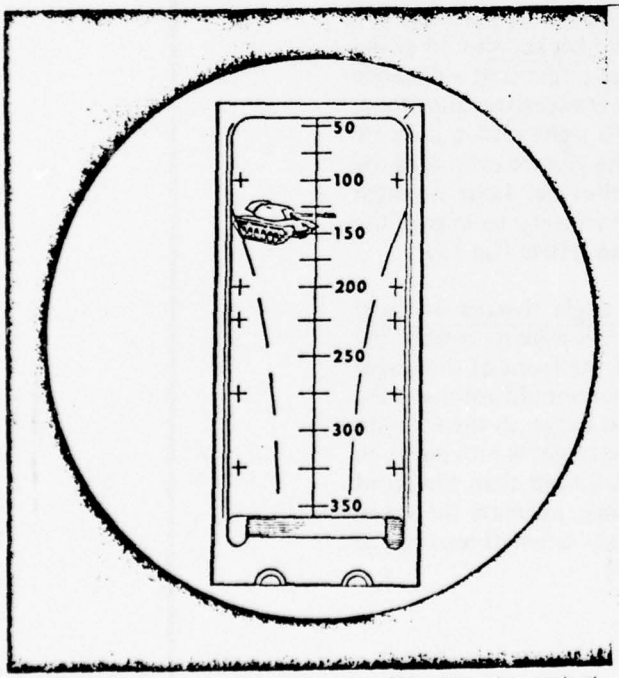

Figure 16. Target moving toward gunner, 150 meters, at an angle of 45 degrees or less.

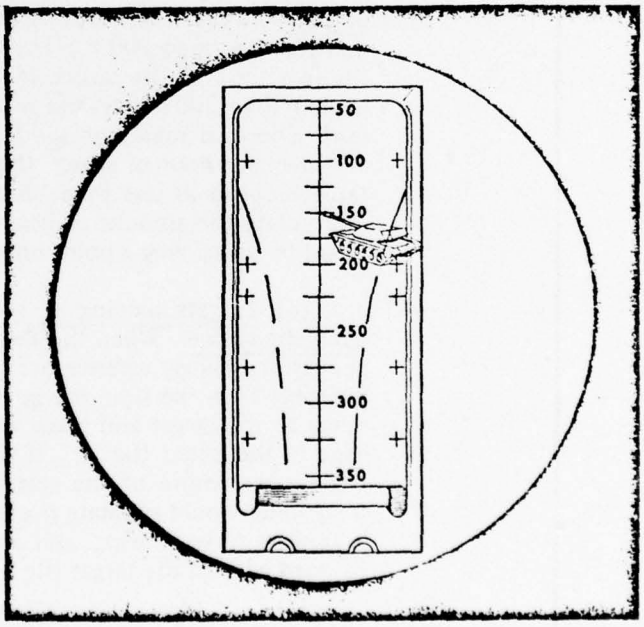

Figure 17. Target moving away from gunner, 175 meters, at an angle of 45 degrees

Figure 1. LAW sighting procedures for engaging moving targets (from FM 23-33, July 1970) (2).

4. For targets at an angle of 45 degrees or less, the crossing speed can vary from 0.7 to 0.0 times actual target speed, so why is only one type of lead (centerline on forward edge of the target) specified?

5. For targets at an angle of 45 degrees or more, why should the gunner estimate target speed when only one type of lead (1/2 lead on forward edge of target) is specified, regardless of target speed?

6. For the target conditions in "5," why does Figure 17 in FM 23-33 (2) show less than 1/4 lead applied to the forward edge of the target?

There is a different and more easily understood rule for leading a moving target with the LAW--the "common-lead" rule. This rule may have been a modification of the rule shown in FM 23-11 (1) and (11). It was incorporated into a draft LAW training aid developed by the USAIC, which is illustrated here in Figure 2. Although different from the set of rules described previously, the "common-lead" rule is still inadequate. First, the rule applies only for one target speed, 15 mph; second, it is unlikely that the gunner will have an opportunity to use it because, unless he is elevated above the target, his estimate of its true speed will be highly inaccurate; and third, the "common-lead" rule is incorrect.

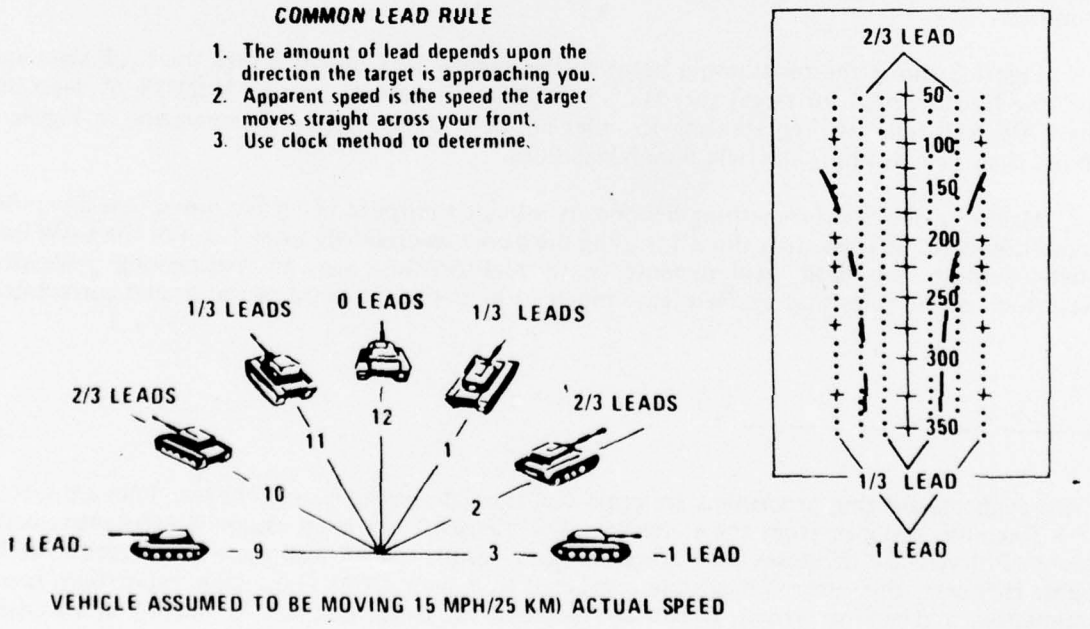

Figure 2. The "Common-Lead" Rule as applied to the LAW (from USAIS LAW Training Aid).

Apparent target speed is proportional to the sine of the target's aspect angle. For a 60-degree target aspect (10 o'clock and 2 o'clock), apparent speed is about 0.9 times its true speed; and for a 30-degree target aspect (11 o'clock and 1 o'clock), it is 0.5 times true speed. Therefore, where the "common-lead" rule calls for 2/3 lead, a full lead would be more correct; and where 1/3 lead is specified, 1/2 lead should be applied. However, the fact that the "common-lead" rule is incorrect is only of academic interest, because it is unlikely that the target will be so obliging as to travel only at a 15-mph speed.

B. Causes of the Difference Between Sighting Procedures

Procedures for engaging moving targets with the other weapons are optimum[b] because, if used correctly, they direct rounds toward the target's center, thus maximizing hit probability. By specifying some other aiming point, rather than the target's center, the LAW sighting procedures give less effectiveness than the optimum procedures. However, it was necessary to use a different and less effective set of procedures for the LAW because of an incompatibility between infantry requirements for lead and the maximum allowable size of the sight.

Although there appears to be no written history of the development of the LAW sight, informal conversations with people who worked on the program disclose that, at the start of the development cycle for the M72 LAW, the sight contained only range lines. During testing, lead lines were added so the weapon could be used effectively against moving targets.[c] The infantry required a weapon capable of leading a 15-mph target. However, a true 15-mph lead line would have required a reticle about 66mm wide, which would not fit on the weapon. Therefore lead lines were placed near the edges of the existing reticle, and the sighting procedures were modified.

Figure 3 shows the relationship between the angular lead designed into the LAW sight and the true lead required for target speeds of 5, 10, and 15 mph. Although FM 23-33 (2) describes the LAW lead lines as "representing 15 miles per hour target speed," interpolation in Figure 3 shows that they are approximately 6-mph lead lines.

Making a device do something beyond its intended purpose often requires a new and more complicated set of rules than those for using the device as originally intended. For the LAW lead lines--assuming the lead requirements were realistic--this was an engineering necessity. Nevertheless, the rules that evolved leave much to be desired in terms of clarity and correctness.

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[b]Although the sighting procedures are optimum, the sight design is not. The lead lines are spaced at a fixed-mil distance from the centerline at all ranges. Thus, they assume a constant-velocity round. But velocity decreases with range and, as a result, a small lead error is designed into the sight. However, this error is negligible compared to gunner errors (e.g., range estimation, speed estimation, and aiming errors), and to the fact that the target may not be moving in a straight line, or at a constant velocity, or at a constant range.

[c]Stadia lines were added later in the mistaken belief they would help the gunner measure target range (3, 5, 10).

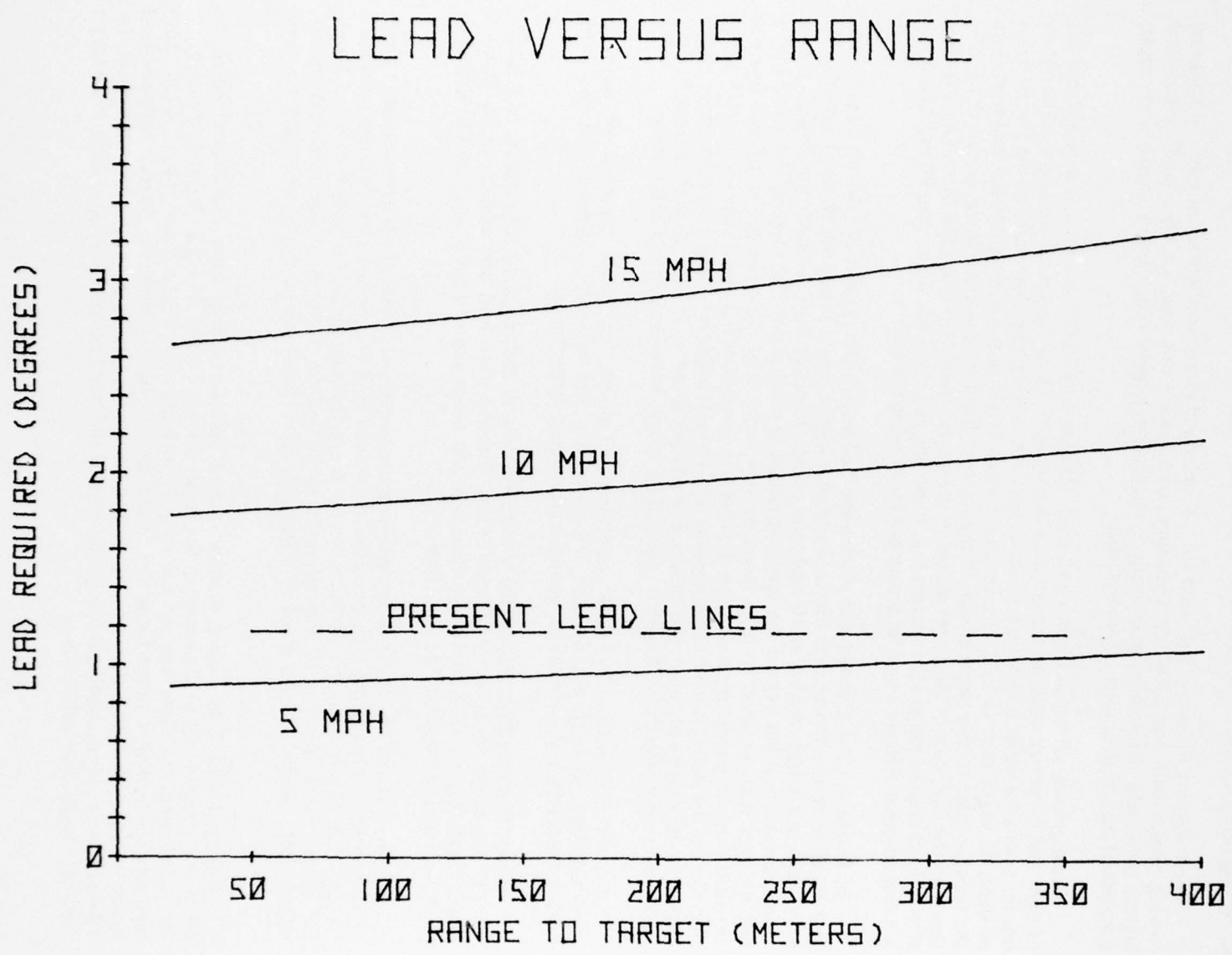

Figure 3. Lead required to hit a moving target with the M72A2 LAW.

C. Hitting Performance Versus Amount of Lead and Target Speed

The foregoing illustrates the need for a simpler and more complete set of rules for engaging moving targets with the LAW. As a starting point toward this goal, a LAW round's theoretical impact point was determined graphically for tank-size targets with various speeds and ranges, amounts of lead, and aimpoints on the targets.

These graphs, shown in Figures 4 through 10, assume a 20-foot-long target moving from left to right and perpendicularly to the gunner's line of sight. These figures can also be used to obtain impact points for other target sizes, or for targets not moving perpendicularly to the gunner's line of sight. To make such conversions, construct a new target of the appropriate size and start from the forward edge of the target shown in the figures when lead is applied there, or center the new target on the midpoint of the target shown in the figures when lead is applied there. However, the effect of a change in range with a target that is moving at some angle other than 90 degrees--which is a second-order effect--cannot be accounted for in using the figures.

In Figure 4, curve 1 shows that placing the lead mark on the center of a 5-mph target results in a hit close to the center over the entire target range. Curve 2 shows the effect of applying the same lead to a target moving at 10 mph; the point of impact shifts towards the target's rear as range increases and lies behind the target at ranges beyond about 220 meters. This curve points out the fact that, in order to hit a target moving faster than the speed the single-lead line was designed for, the gunner must position the lead line forward of the target's center. Curve 3 shows that placing the lead line on the leading edge of a 10-mph target results in a hit somewhere on the target out to a range of about 350 meters. For a target speed of 15 mph, as seen in curve 4, extra lead equal to the target's full length is required for ranges between 200 and 350 meters.

Figures 5 through 10 show target-impact points for other methods of applying lead--including no lead, leading with the centerline, and one-half, one-third, and two-thirds lead--and the effect of errors in the gunner's estimate of target speed.

Figure 5 shows that placing the lead line on the target's forward edge results in a miss in front of the target for speeds of 5 mph or less. With the same lead and speeds up to about 8 mph (Figure 6), a round impacts further from the target center than if the lead line had been positioned on the target's mid-point (Figure 7).

Figure 7 shows the effect of underestimating target speed when the gunner uses the correct procedure for applying lead (i.e., positions the proper lead line on the target's center). Curves 3 through 5 in Figure 8 show a similar effect for overestimating speed. For speeds of 0 and 2 mph, the round lands in front of the target at ranges greater than about 150 and 225 meters, respectively. Similarly, for a speed of 9 mph, the round lands behind the target at ranges beyond 275 meters.

Curves 1 and 2 of Figure 8 show impact points resulting from positioning the sight's centerline (range line) on the center of the target. Curves 1 and 2 of Figure 9 show similar results for positioning the centerline on the target's forward edge. For a 5-mph target speed, both methods for leading a target cause the round to land further from the target's midpoint--and lower the hit probability--than placing the lead line on the target's center. On the other hand, for 10-mph target speeds, leading the target by placing the lead line on the forward edge of the target yields the higher hit probability.

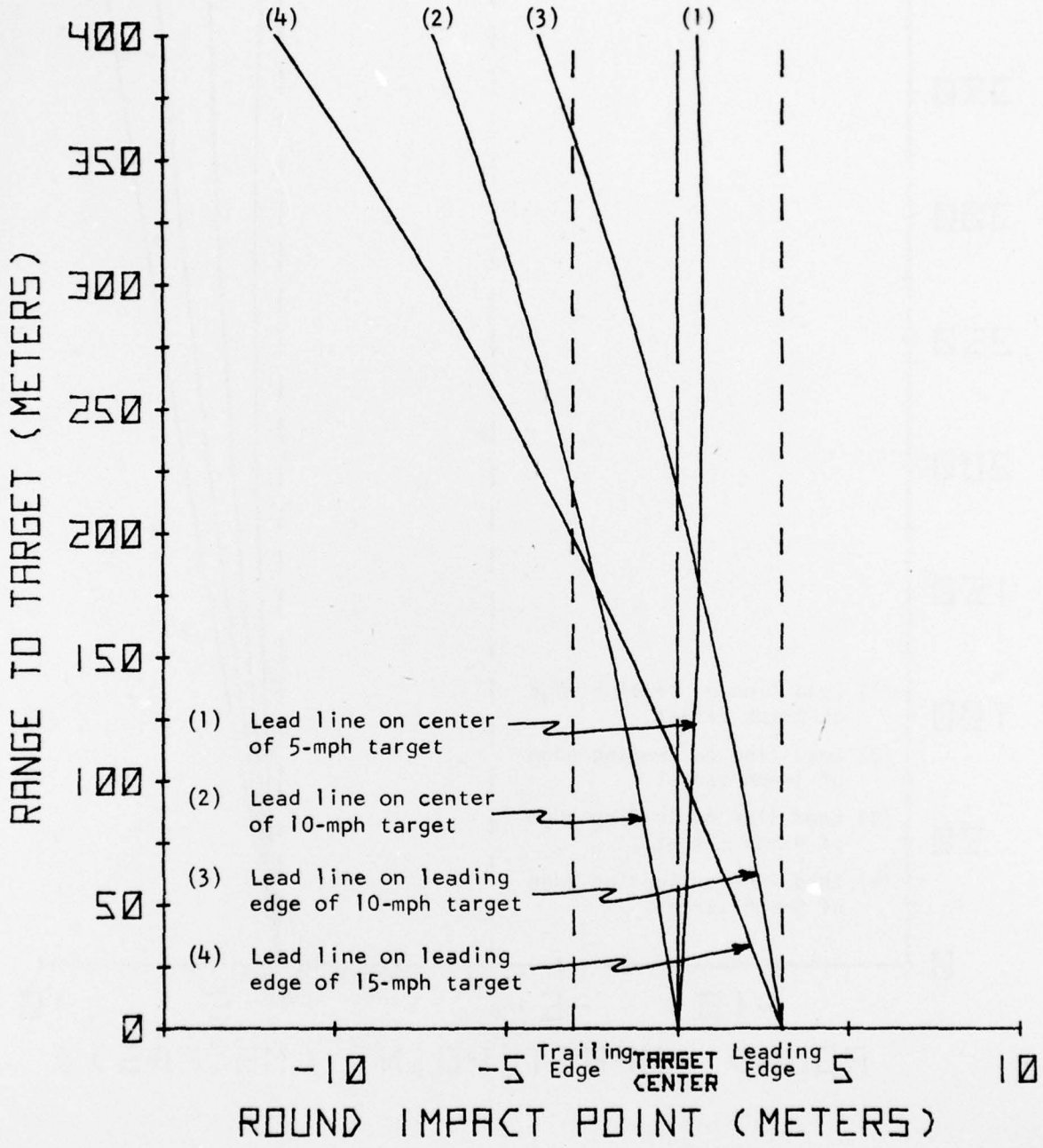

Figure 4. LAW round point-of-impact on a twenty-foot-long target moving perpendicularly to the gunner's line of sight--Three speeds and two types of lead.

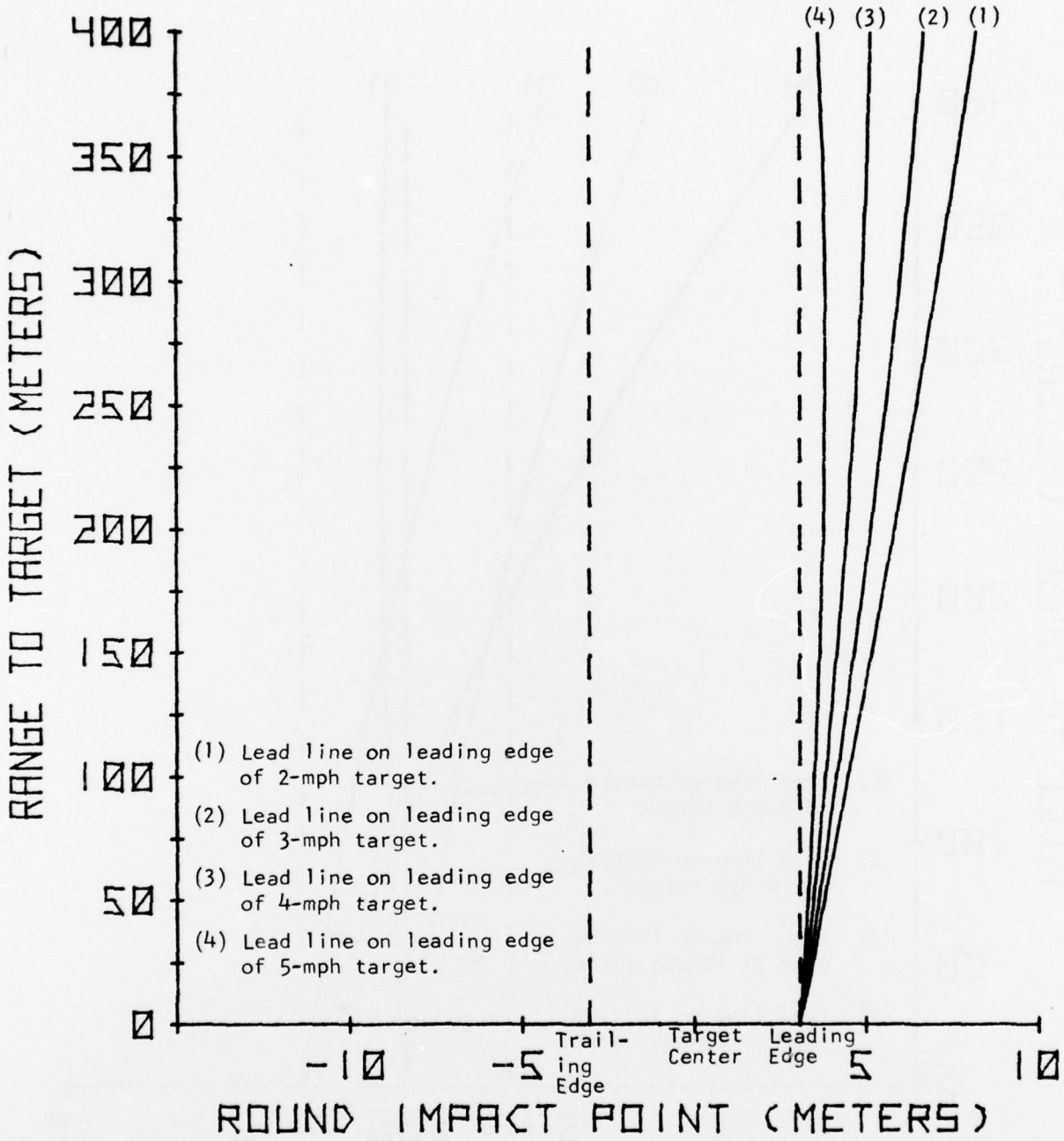

Figure 5. LAW round point-of-impact on a twenty-foot-long target moving perpendicularly to the gunner's line of sight--Lead line on leading edge of 2-5 mph target.

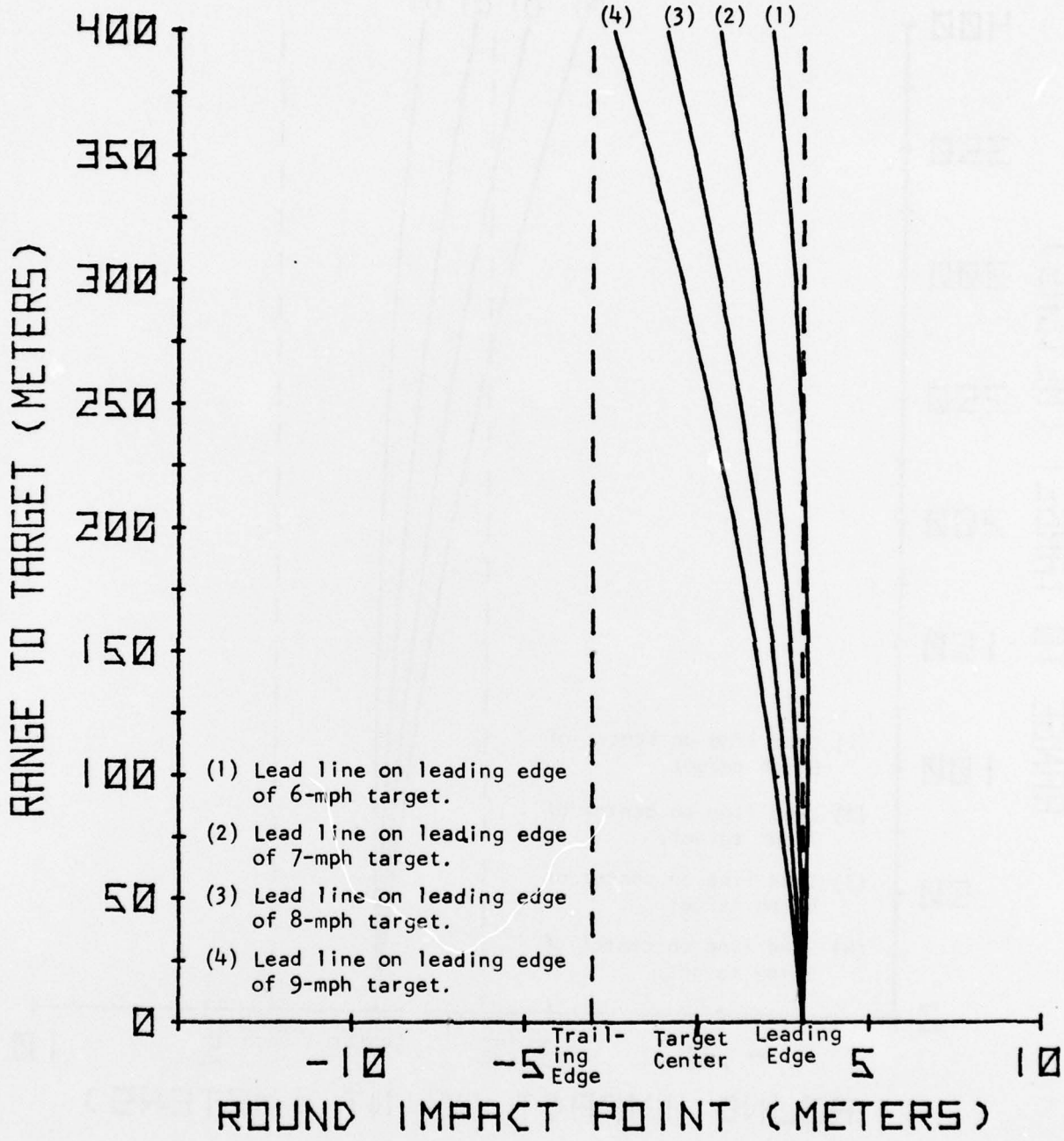

Figure 6. LAW round point-of-impact on a twenty-foot-long target moving perpendicularly to the *gunner's line of sight--Lead line on leading edge of 6-9 mph target.*

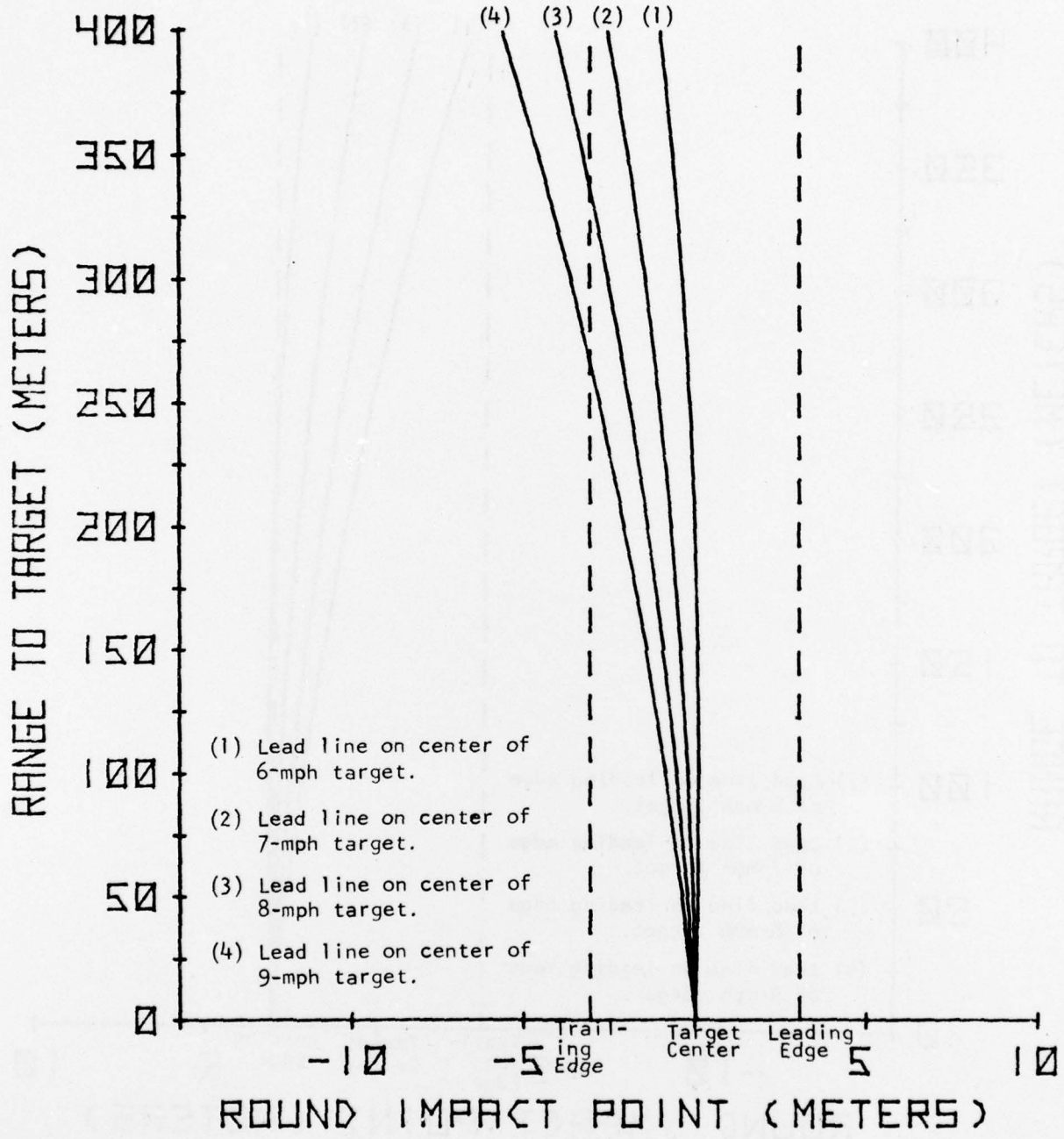

Figure 7. LAW round point-of-impact on a twenty-foot-long target moving perpendicularly to the gunner's line of sight--Lead line on center of 6-9 mph target.

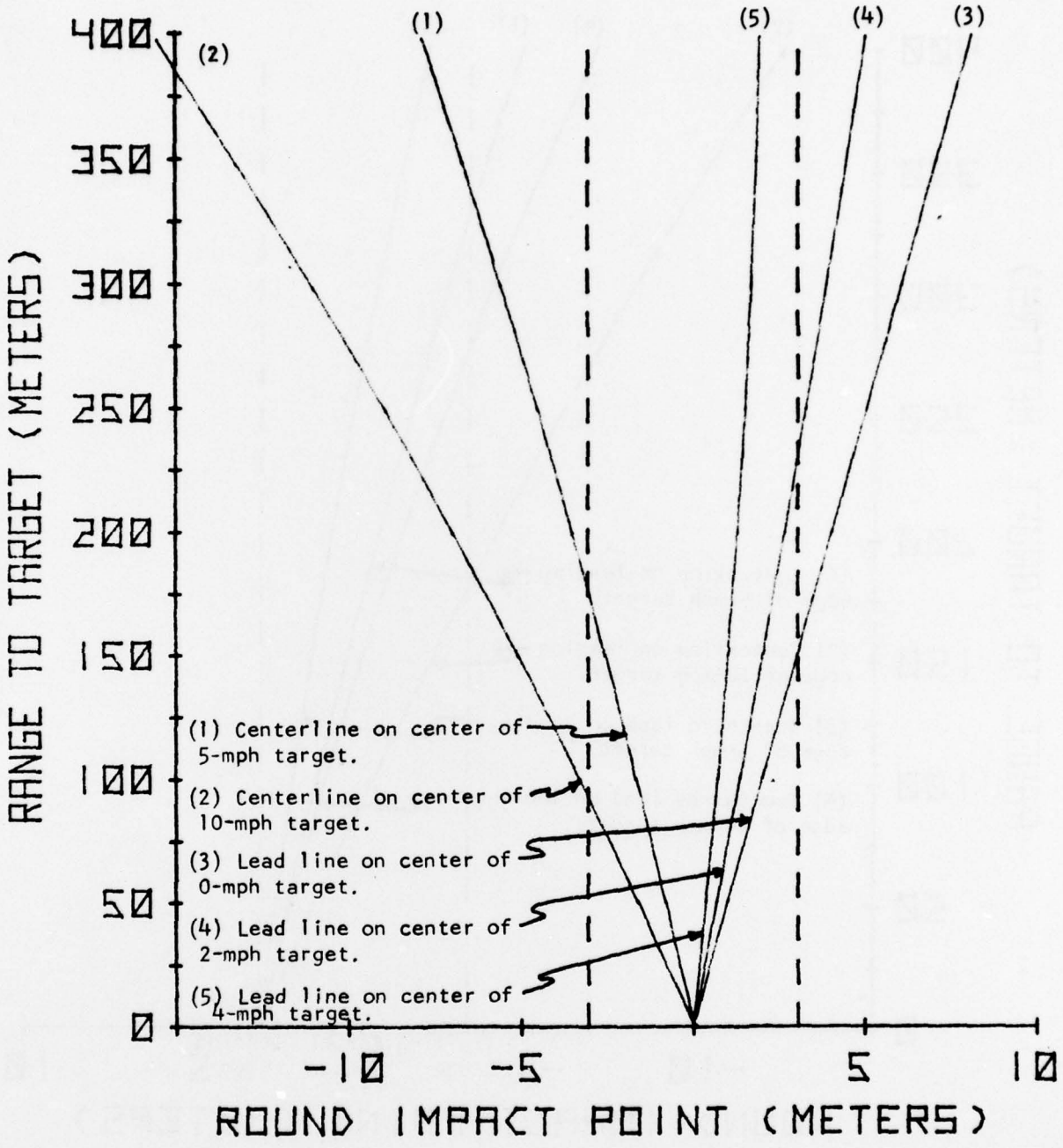

Figure 8. LAW round point-of-impact on a twenty-foot-long target moving perpendicularly to the gunner's line of sight--Aiming point at the target's center.

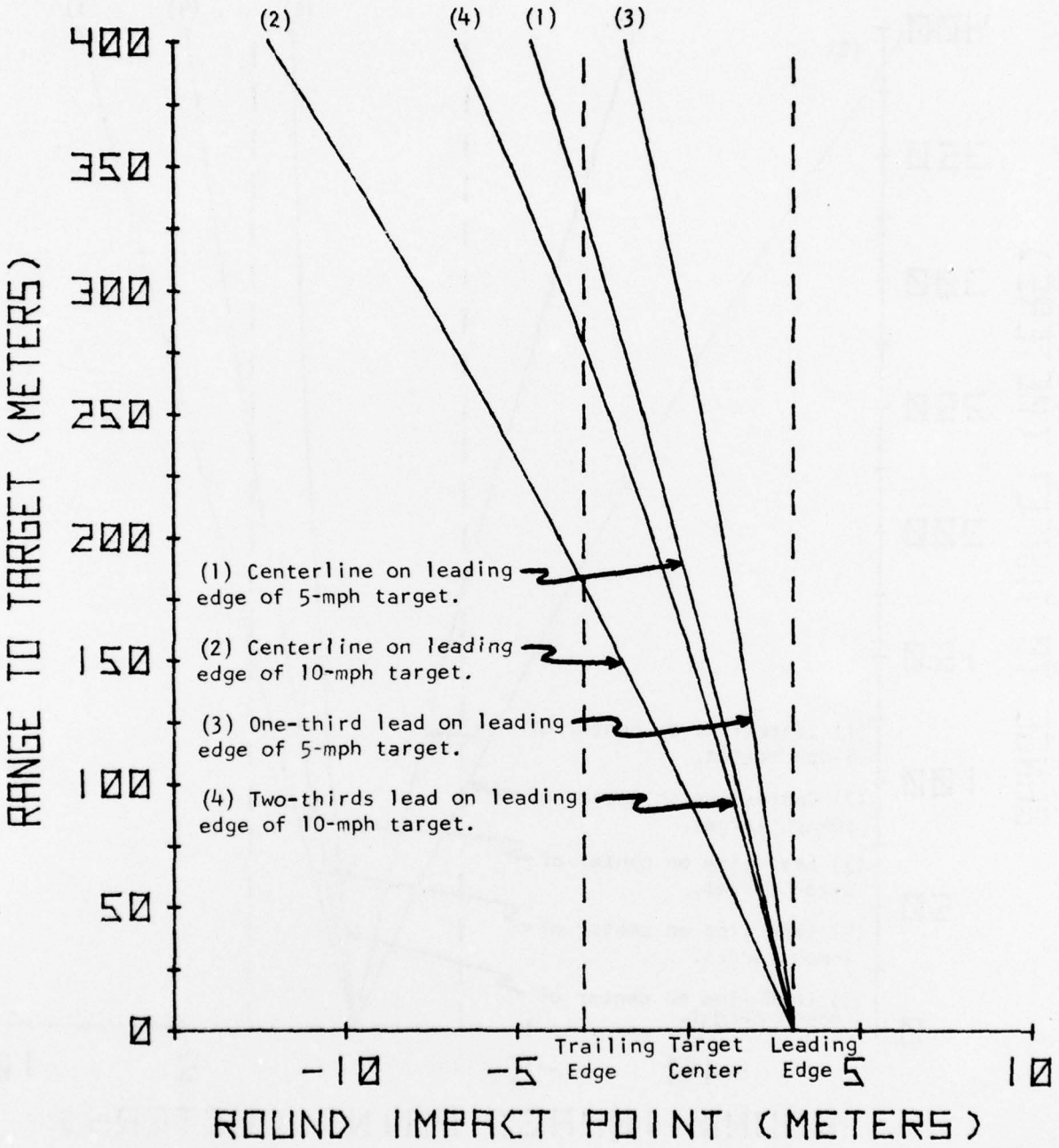

Figure 9. LAW round point-of-impact on a twenty-foot-long target moving perpendicularly to the gunner's line of sight--Centerline and interpolated point on targets leading edge.

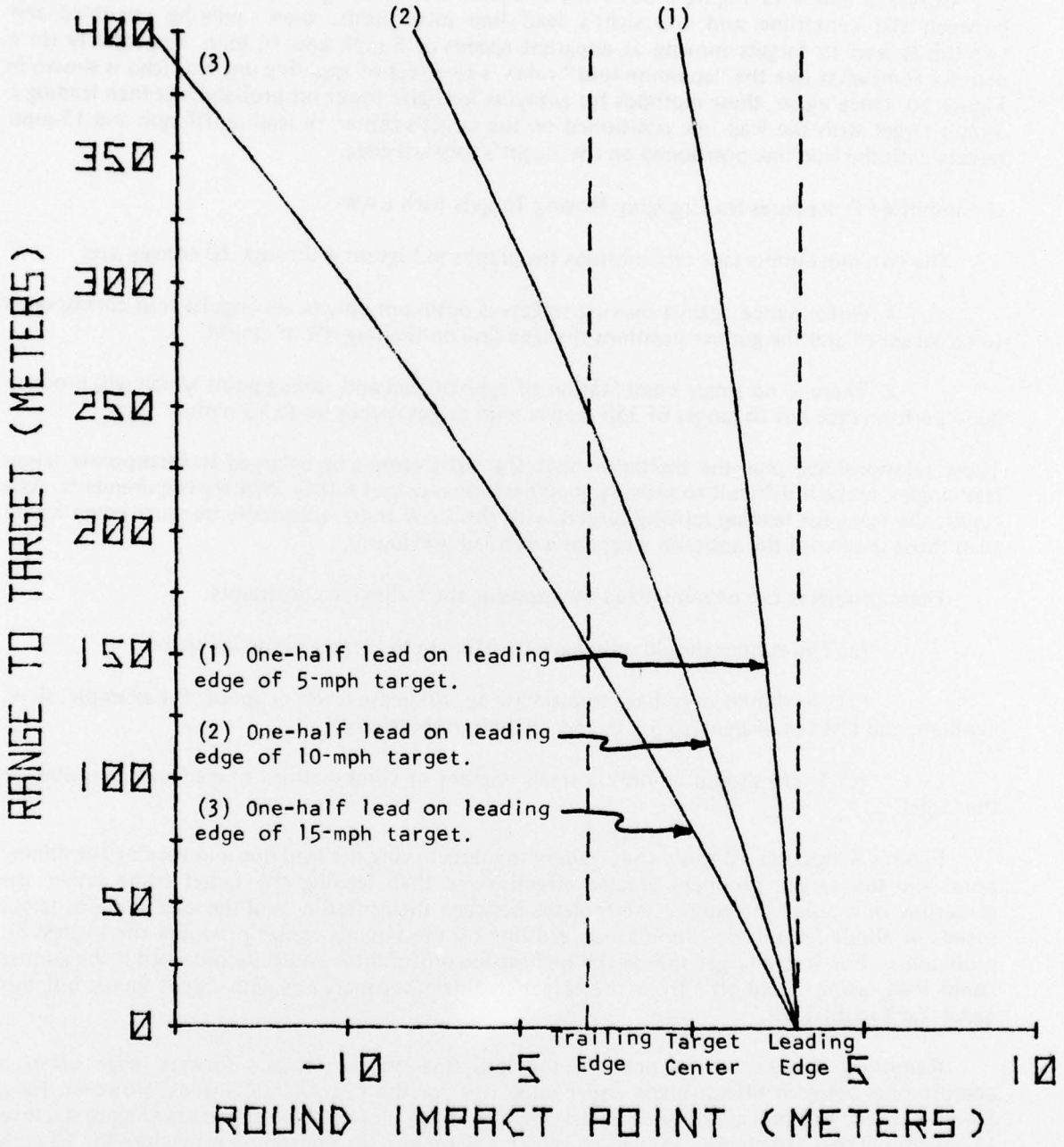

Figure 10. LAW round point-of-impact on a twenty-foot-long target moving perpendicularly to the gunner's line of sight--One-half lead on target's leading edge.

Curves 3 and 4 in Figure 9 show the effect of interpolating lead by splitting the distance between the centerline and the sight's lead line into thirds, then applying one-third and two-thirds lead to targets moving at apparent speeds of 5 mph and 10 mph, respectively (in a manner somewhat like the "common-lead" rule). The effect of applying one-half lead is shown in Figure 10. Once again, these methods for applying lead give lower hit probabilities than leading a 5-mph target with the lead line positioned on the target's center, or leading 10-mph and 15-mph targets with the lead line positioned on the target's forward edge.

D. Simplified Procedures for Engaging Moving Targets with LAW

The two most important relationships the graphs in Figures 4 through 10 convey are:

1. Performance against moving targets is optimum only when angular lead corresponds to target speed and the gunner positions the lead line on the target's midpoint.

2. There is no single combination of type of lead and aiming point which will produce good performance out to ranges of 350 meters with target speeds up to 15 mph.

These relationships, plus the limitation that the sight cannot be enlarged to incorporate larger lead angles, make it difficult to provide good performance and satisfy infantry requirements. As a result, the rules for leading moving targets with the LAW must necessarily be more complicated than those used with the antitank weapons described previously.

These problems can be minimized by imposing the following constraints:

(a) The gunner should only have to estimate the target's crossing speed.

(b) He should only have to estimate approximate levels of speed: for example, slow, medium, and fast (equivalent to 5, 10, and 15 mph, respectively).

(c) There should be only a small number of combinations of lead and aimpoint on the target.

Figures 4 through 10 show that leading the target using the lead line and varying the aiming point on the target produces greater effectiveness than leading the target using either the centerline or a point the gunner interpolates between the centerline and the lead line. For target speeds of about 5 mph, positioning the lead line on the target's center produces the highest hit probability. For faster target speeds the highest hit probability would be obtained if the gunner could lead, using "hold-off" from the target's center that increases with target speed; but this task is far too difficult.

Requiring the gunner to position the lead line on the target's forward edge offers a compromise between effectiveness and complexity for the faster target speeds. However, for a 15-mph speed, this procedure can be used only for ranges closer than 200 meters (Figure 4, curve 4). Assuming that targets will be engaged out to 350 meters, a compromise procedure for 15-mph speed and 200- to 350-meter range is requiring the gunner to apply additional lead (i.e., hold-off) equal to the length of the target.

The discussion above allows us to derive two sets of procedures for engaging moving targets with the LAW: one for target ranges out to 200 meters, and the other for ranges out to 350 meters. In addition, the gunner's procedures for selecting the proper lead line, and the correct range/superelevation point on the lead line, can be made more intelligible than those in FM 23-33 (Figure 1) (2).

These "Simplified Procedures for Engaging Moving Targets With the LAW," are shown in Figure 11. Depending on whether or not engagement range is limited to 200 meters, "A" in the Figure can be combined with "B" or "C" and used to replace the current procedures (Figure 1) (2).

TRAINING IMPLICATIONS

In developing these new procedures for engaging moving targets with the LAW, two of the general areas of human factors (7, p. 3) were examined: 1) the human-performance requirements, and 2) the design of the equipment in the man-machine interface. A third factor--the type and amount of training necessary to achieve reliable human performance--was not directly examined, although the results of this investigation have implications for training.

It is unlikely that the average LAW gunner can be trained to either understand or remember how to use the current procedures for engaging moving targets. There are experimental findings (4, pp. 26 and 27, and 13 p. 14) to show that this is not merely supposition. Although there are no similar data for the new procedures, the fact that the new procedures are simpler suggests that LAW trainees would learn (and remember) them more easily. Also, it may take less training time to teach the new procedures, as compared to previous procedures, and with the added benefit that reliable human performance is more likely to be achieved.

CONCLUSIONS

The lead lines on the LAW sight reticle are designed for a target speed of 6 mph.

The current rules for leading targets moving at speeds up to 15 mph are incomplete, complex, and confusing; and, if used, their effectiveness is less than could be realized with a greatly simplified set of rules.

It may also require less training time to instruct potential LAW gunners with the simplified rules proposed here than with current rules.

RECOMMENDATION

The rules described in this report (Figure 11) for leading moving targets with the LAW should be adopted to increase LAW-gunner effectiveness.

A. Steps the gunner must take to lead a moving target:

1. Estimate[a] the range to the target.

2. Locate the corresponding range line on the sight.

3. Estimate the target's crossing speed.

4. Imagine a vertical line (lead line) connecting the lead crosses on one side of the reticle.

5. If the target is moving from left to right, use the left lead line; and if the target is moving from right to left, use the right lead line.

6. Identify on the lead line the point across from the chosen range.

7. Place that point over the aiming point on the target according to the rules below.

B. Rules for applying lead to a moving target--assuming engagement ranges out to 350 meters:

1. Slow speed (about 5 mph)	–	Place the lead line on the center of the target for all target ranges.
2. Medium speed (about 10 mph)	–	Place the lead line on the forward edge of the target for all target ranges.
3. Fast speed (about 15 mph)	–	Place the lead line on the forward edge of the target for ranges out to 200 meters, and in front of the forward edge of the target a distance equal to the length of the target for ranges greater than 200 meters.

C. Rules for applying lead to a moving target--assuming engagement ranges out to 200 meters:

1. Slow speed (about 5 mph)	–	Place the lead line on the center of the target.
2. Fast speed (about 10 mph or greater)	–	Place the lead line on the forward edge of the target.

[a]Stadia lines should be ignored; estimated range with unaided visual techniques or with range/sector cards. Results from HEL and USAIB experiments (1, 9, 13) show conclusively that stadia provide no additional range-estimation capability.

Figure 11. Simplified procedures for engaging moving targets with the LAW.

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